OPTICAL WAVEGUIDE DEVICE, LAYERED SUBSTRATE AND ELECTRONICS USING THE SAME

This application is a continuation of International Application No. PCT/JP03/09727 filed on July 31, 2003, which claims the benefit of Japanese Patent Application No. 225467/2002, filed August 2, 2002.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an optical waveguide device having an optical waveguide such as optical waveguide layer for optically coupling signals between electronic chips on an electric circuit board or between electric circuit boards, for example. The present invention also relates to a layered substrate made up of such a device integrated with an electric circuit board, and an electronic equipment using the same.

Related Background Art

In recent years, performance of portable devices such as personal computers, cellular phones and personal digital assistants (PDA), and digital audio/video (AV) apparatuses has been making rapid progress, and interconnection between them is realized in any frequency bands using a combination

of wireless and wired connections. There is, therefore, an urgent need to address any faulty operation of digital devices due to, for example, electromagnetic interference (EMI) from circuit boards, interference by an external electromagnetic wave, and signal integrity (SI) disturbance by faulty connections. These problems associated with electromagnetic waves require the products to satisfy the regulatory standards imposed by the Radio Law before shipment, and the developing costs to fulfill the requirement is increasing year by year. It is expected that the optical wiring, which inherently induces no electromagnetic wave, may essentially eliminate the bottleneck. With the prospect that a high-speed connection environment such as FTTH will be available even at home in future, faulty operation, noise disturbance and the like of high-speed electronics must be avoided supposing they may be connected to different types of ground environment. The optical connection is one of potential solutions because it provides electrical isolation from the ground in a simple manner.

To this end, a variety of ways has been proposed for optical wiring means. Among them, a method of using an optical waveguide sheet to make a bus connection among a plurality of electric circuit boards in an information processing apparatus 1100

has been disclosed in the Japanese Patent Application Laid-open Nos. 09-270751 and 10-206677. In those disclosures, an optical waveguide sheet 1101 and electric circuit boards 1120 are coupled together independently and vertically, as shown in FIG. 8A. Optical elements 1132, 1142 are mounted at input and output ports 1130, 1140 on an electric circuit board 1120, and are adapted to couple with the optical waveguide sheet 1101 via mirrors 1133s inclined at an angle of 45 degrees. In this example, the optical waveguide sheet 1101 constitutes a planar slab waveguide, and multiplexes signals in a direction along the layers. In FIG. 8B, reference numeral 1123 denotes an electronic circuit, 1131 and 1141 denote circuits for optical elements, 1133 an input for signal light, and 1134 an output for signal light.

Although an optical waveguide sheet as shown in FIGS. 8A and 8B leads to cost savings because it mitigates the problems of fabrication and alignment, it requires one sheet for each bit of a bus. This limits its application because a parallel-to-serial conversion and/or multilayer sheet is required to accommodate a multi-bit bus. Although several systems to multiplex multi-bit signals using one single sheet have been studied, they resulted in a complex system because signals are separated according to the signal strength or wavelength.

SUMMARY OF THE INVENTION

An optical waveguide device according to the present invention comprises an optical waveguide layer and a light-receiving element, wherein the optical waveguide layer is provided with a light direction-altering means for altering the direction of light propagated in the optical waveguide layer and for directing the light to the light-receiving element, and the light-receiving element is provided with a plurality of light-receiving portions, each of the light-receiving portions being capable of receiving signals independently. According to one embodiment of the present invention, the waveguide device comprises an optical waveguide layer being a planar slab waveguide for propagating light to exchange signals using light, wherein the optical waveguide layer is provided with a light-receiving element and a light direction-altering means to direct the light to the light-receiving element at a certaom angle to the optical waveguide surface (for example, a direction perpendicular to the plane of the optical waveguide layer) of the optical waveguide layer, and the light-receiving element is composed of an array of light-receiving portions which are operable independently, where the light direction-altering means and the light-receiving element are positioned in such a manner that the light propagated

through the optical waveguide sheet and redirected by the light direction-altering means is received by the light-receiving portions of the light-receiving element. According to this configuration, the signal processing part can receive signals discriminating the light-transmitting sources because the distribution of light intensity received at the light-receiving portions of the light-receiving element varies depending on the location of the light-transmitting sources, which realizes a multiplexed optical wiring of unrestricted wiring architecture without using a complex waveguide structure.

The layered substrate according to the present invention is characterized in that an optical waveguide device described above is mounted on an electric circuit board (as well as to an electronic chip) so that electric connections can be formed, whereby all or part of the signals from the electric circuit are interconnected by exchanging optical signals through the optical waveguide device to drive electronics. More specifically, at least one optical waveguide device and one electric circuit board may be layered and through-hole vias formed in all or part of the layered optical waveguide devices to connect electric wirings to the electric circuit board in order to drive optical elements of each

optical waveguide device. The optical waveguide device may be embedded within an electric circuit multilayer substrate, or the waveguide devices themselfs may be multilayered and connected to an electric circuit board and electronic chips.

The electronic device according to the present invention uses the layered substrate described above, and the system is operated with optical wirings mixed with multi-bit wirings between electronic chips such as CPUs and memory devices.

Thus, by layering an optical waveguide device to an electric circuit board to replace part of the wirings of an electric board provided with LSI etc. with an optical wiring, improved functionalities and EMI measures can be achieved in electronics requiring high-speed multi-channel wirings in a cost effective manner. Specifically, the layered substrate according to the invention will be important for designing next generation portable devices with mixed wireless systems, or for designing CPU boards operated with higher clock rates.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of an optical waveguide device of Example 1 according to the invention;

FIG. 2 is a plan view illustrating a light-

receiving portion and light direction-altering structure of an optical waveguide device of Example 1 according to the invention;

FIGS. 3A, 3B, 3C, 3D, 3E, 3F and 3G showing sectional views illustrating processes of fabricating an optical waveguide device of Example 1 according to the invention;

FIG. 4 is a perspective view illustrating an optical waveguide device of Example 2 according to the invention;

FIG. 5 is a perspective view illustrating an optical waveguide device of Example 3 according to the invention;

FIG. 6 is a sectional view of a combined electric/optical substrate that combines an optical waveguide device of Example 4 according to the invention with an electric circuit;

FIG. 7 is a perspective view of a combined electric/optical substrate with high-speed signal connections of Example 5 according to the invention; and

FIGS. 8A and 8B illustrate an example of a conventional optical waveguide device using a planar waveguide sheet.

DETAILED DESCRIPTION OF THE PREFERRRED EMBODIMENTS

The present invention provides optical

waveguide devices, layered substrates and electronics devices having configurations as described above. The above-described basic configuration includes the following embodiments.

According to one embodiment, the optical waveguide layer may further be provided with a light-emitting element and a second light direction-altering means for altering the direction of light incident at a certain angle to the in-plane direction of the optical waveguide layer (for example, perpendicular to the plane of the optical waveguide layer), and the second light direction-altering means is positioned in such a manner that the direction of the light emitted from the light-emitting element can be altered by the second light direction-altering means to enter the optical waveguide layer. In the present invention, an optical waveguide layer means a layer that can transmit light signals in the plane, including those in a sheet form. The light direction-altering means for light-emitting element may couple light optically to the optical waveguide in all directions in the plane of the waveguide layer as shown in FIG. 1, it may couple light to the optical waveguide as a directional beam as shown in FIG. 4, it may narrow the emission angle of optical signals, for example, to 90 degrees, in order to transmit light signals only to a certain area of the

optical waveguide as shown in FIG. 5. By narrowing the emission angle of the optical signals, long transmission distance and/or high transmission rate is obtained in comparison with two-dimentional all-direction coupling. Further, different types of light direction-altering means may be provided for light-emitting elements so that the above three transmission systems coexist in one light waveguide device: in this case, a plurality of signals can be multiplexed in the same optical waveguide sheet to be detected by a light-receiving element provided with light-receiving portions arranged in a proper array.

For example, the light-receiving element may have at least plural light-receiving portions arranged in a circle, and a light direction-altering means for it can receive light transmitted from every direction in the optical waveguide layer, so that the intensity of light received by respective light-receiving portions varies depending on the position of the transmitting source of the transmitted light, which enables signal reception with discrimination of the source. In one specific embodiment, at the transmitting end a light signal is propagated in all directions in the waveguide layer as shown in FIG. 1, and at the receiving end, the signal is received and transmitted by a hemispheric, conic or pyramid shaped light direction-altering means to a light receiving

element provided with light receiving portions mounted on its surface in a circle around the center corresponding to the top point of the altering means as shown in FIG. 2. This allows positional identification of the transmitting source by the receiving element, so that one receiving element can receive multiplexed signal, discriminating signals from plural transmitting sources. The number of channels may of course be increased by multiplying the optical waveguide layers with mixed positional multiplex.

Alternatively, the light-receiving element have light-receiving portions arranged linearly, and the light direction-altering means for it can receive light transmitted from a specified region of the optical waveguide layer. Since the intensity of light received by respective light-receiving portions varies depending on the position of the transmitting source of the transmitted light, this configuration allows signal reception with discrimination of the transmitting source.

Alternatively, incident light from the light-emitting element propagates in every direction in the optical waveguide layer, and the light receiving element provided with light receiving portions arranged in a circle detects the signal with positional discrimination of the light emitting

element, so that one light receiving element can receive multiple optical signals from multiple emitting elements at a time in the same optical waveguide layer. Further, it may be arranged in such a manner that incident light from the light-emitting element is propagated in a specific emission angle in the optical waveguide layer, and the light receiving element provided with light-receiving portions arranged in a circle detects light signals with positional discrimination of the transmitting sources. Thus one light receiving element can receive multiple optical signals from multiple emitting elements at a time in the same optical waveguide layer.

It is also possible to configure an optical waveguide device in such a manner that light emitted from a light emitting element is propagated as parallel beams in the optical waveguide layer in a certain direction, and detected by a light-receiving element having linearly arranged light receiving portions with positional discrimination of the emitting element, whereby one light receiving element can receive multiple optical signals from multiple emitting elements at a time in the same optical waveguide layer. Specifically, plural directional beams emitted from a transmitting element are optically coupled to an optical waveguide, and a light-receiving element provided with plural light-

receiving portions in linear arrangement where respective light receiving portions are aligned to receive beams redirected by a light direction-altering means such as a long mirror inclined at an angle of 45 degree. Thereby multiplexed signals can be received by one light-receiving element composed of linearly arranged light-receiving regions.

It is also possible to configure an optical waveguide device containing plural light-emitting elements that emit light in various propagation forms as described above, and plural light receiving elements that receives light in various manner as described above in one waveguide layer in mixture, whereby plural optical signals are simultaneously exchanged in one waveguide layer (see the arrangement shown in FIG. 5).

The optical waveguide device of the present invention may further include an active relay means (see the reference numeral 235 in FIG. 7) that converts an optical signal to an electric signal and then to an optical signal again: light directed by a light direction-altering means to propagate in the optical waveguide layer is subjected to optical/electric (OE) conversion to reshape the signal, then to electric/optical (EO) conversion to reproduce an optical signal which is further redirected by a light direction-altering means to

propagate in the optical waveguide layer in a predetermined propagation manner.

Particular examples will now be described with reference to drawings in order to clarify embodiments according to the present invention.

EXAMPLE 1

FIG. 1 is a perspective view of an entire optical waveguide device according to this Example of the invention. An optical waveguide layer (optical waveguide sheet) 11 of good processability is produced using two kinds of transparent polymer materials different in refraction index in combination to provide a flat flexible sheet that can easily be bent, where a core layer 1 (a region of relatively high refractive index) and upper and lower clad layers 2 (regions of a relatively low refractive index) are formed in a total thickness of several hundred microns. In this Example, polycarbonate Z (PCZ) having a refractive index of 1.59 is used for the core layer 1 of 100 μm thick, and ARTON with a refractive index of 1.53 is used for the clad layers 2 of 100 μm thick. The materials and thickness are not limited to these.

Surface light-emitting elements 6a-6c such as LED and surface-emitting laser are mounted as a light source, and connected to electrodes 4, 5 formed on the optical waveguide layer 11 to drive the elements.

The surface-emitting laser may be VCSEL, which is prepared, for example, a GaAs/AlGaAs MQW active layer, a spacer layer forming a single wavelength resonator, and AlAs/AlGaAs DBR mirrors (located on either sides of the active layer) are formed on a GaAs substrate using a crystal growth method such as MOCVD.

Under the surface-emitting element 6, a light direction-altering structure 3 being substantially hemispheric is embedded in the core layer 1 of the optical waveguide layer 11 to direct light from the light-emitting element 6 into the optical waveguide layer 11 as shown by the reference numeral 14. In this example, the center of light-emission part of the light-emitting element 6 is aligned to come just above the top point of the substantially hemispheric structure 3 so that the transmitted light can be propagated in all directions, i.e., in 360 degrees, as shown by the reference numeral 12, in the entire layer 11 constituting a planer slab waveguide.

Part of the light coupled to the optical waveguide layer 11 propagating as a beam of reference numeral 17 in FIG. 1, and reflected upward from the layer 11 by a light direction-altering structure 16 located under a light-receiving element 7, which is similarly surface mounted, so that the optical signal is received by the light-receiving element 7. If the light direction-altering structure 16 is

substantially hemispheric, it can receive from all directions light propagating in the optical waveguide layer 11. Thus such light as shown by the reference numeral 15 can be directed upward by the light direction-altering means 16, and received by the light-receiving element 7. As the light-receiving element 7, Si PIN photodiode (PD) and the like can be used.

In FIG. 1, a part of the mounted optical elements 6, 7 are somewhat protrudent above the surface of the optical waveguide layer 11. They can, however, be fully embedded therein depending on the thickness of the optical element and/or the depth of the guide hole for the optical element.

In this Example, when the light direction-altering structure 16 in the signal receiving end is in a hemispheric shape, the surface region of the light direction-altering structure 16 that reflects light from a transmitting source varies depending on the direction of the transmitting source. Thus a light beam in a certain direction is received only by a light-receiving portion of the light-receiving element 7 locating just above the reflecting surface region of structure 6. As can be seen in FIG. 2, which shows a plan view of a hemispheric structure 32, the reflected light intensity of an incident light coming from a direction 35 is particularly strong

from a region 33 of the hemispheric structure 32, and that of the light from a direction 36 is particluarly strong in a region 34. Accordingly, if the surface of the light-receiving element 37 is mounted with a plurality of light-receiving portions 38 arranged in a circular form around another light-receiving portion 38 arranged to locate just above the top point of the hemispheric structure 32 as shown in FIG. 2, and each of them can independently detect signals, it is possible to identify the position of the transmitting source based on the received light pattern by the light-receiving portions 38. For example, the relationship between each transmitting source and the light intensity pattern may be stored in a memory portion of the circuit, and retrieved to process signals according to a program in the processing portion. Even if there are multiple transmitting sources 6 as shown in FIG. 1, therefore, plural signals can be multiplexed in the same core 1 in the planar slab optical waveguide layer 11 not having linear waveguides. Although a hemispheric shape is used as a structure for altering light direction in all direction covering 360 degrees in this example, a conic or pyramid shape may also be used. The number and/or pattern of the light-receiving portions are not limited to those shown in FIG. 2.

Next, an exemplary fabricating process of an optical waveguide device of this example is described with reference to FIGS. 3A, 3B, 3C, 3D, 3E, 3F and 3G. In this example, a light direction-altering structure embedded within an optical waveguide layer is made by metal plating. In FIG. 3A, Cr/Au (21 and 22 respectively) is deposited on a glass substrate 20 as whole surface electrode for plating. The substrate is not limited to glass, and may be Si, ceramic and resin, etc. In FIG. 3B, photoresist 23 is patterned by photolithography, and a window 24 for plating is formed at any desired location where a light direction-altering structure is to be formed. In this example, the size of the window 24 is 5-10 μm in diameter. In FIG. 3C, thickening the material beyond the photoresist 23 by plating results in a hemispheric shape as shown by the reference numeral 25. In this example, Ni electrolytic plating was used to create a hemispheric structure 25 having a thickness of 80 μm that is slightly less than 100 μm of the core layer thickness of an optical waveguide sheet: this leads to a diameter of 160 μm. Any size may be obtained by adjusting plating time, etc. to optimize the result depending on a sheet thickness, a type of light source and/or light receiving element.

The plating material may be Cu, Cr, Al, Au and other metal or compound, and heterogeneous materials

may be multilayered. The electroless plating may be used. In FIG. 3D, removing the photoresist 23 reveals a structure that has a hemispheric structure 25 of 160 μm in diameter having a stem (base) of about 10 μm diameter. Although any desired number and pattern of hemispheric structures 25 may be formed by patterning the photoresist 23, if necessary, certain hemispheric structures 25 may be removed by flipping off or by adhering to an adhesive tape. This allows various arrangements of hemispheric structures even if the same photoresist patterning mask was used.

In FIG. 3E, a polymer material as a core layer 26 is formed to embed the hemispheric structure 25 by dipping, casting, dispensing, and the like method. In FIG. 3F, a clad layer 29 having a smaller refractive index than the core layer 26 is then formed on the surface, and a hole 30 is formed for an electrode wiring 27 and for mounting an element. In this example, a sheet of ARTON (trade name), having holes formed by using excimer laser etc. at the sites where the elements are to be mounted, is attached to the surface of the core layer 26. Alternatively, photosensitive resin such as SU-8 (trade name), BCB, etc. may be used and directly patterned to create holes. Since SU-8 has a high refractive index, it should be applied only adjacent to the element

mounting areas. Alternatively, the clad layer 29 can be omitted, hole 30 is processed directly in the core by laser machining controlling the depth for mounting an element. Alternatively, the fitting hole 30 may omitted and the optical element may be directly mounted by flip-chip bonding alignment.

An electrode or electric wiring 27 is a metal wiring such as aluminum, copper, and the like. To create it, vacuum evaporation and lithography technologies may be used to form a wiring pattern with Al, Cu, Ag, Au etc. Alternatively, a conductive paste of Cu, Ag, Au etc. may be applied on the waveguide layer using screen printing to form a circuit conductor pattern, and then the paste may be baked or hardened to form a circuit conductor. Alternatively, a metal foil such as electrolytic copper foil may be layered, and an etching resist of a desired pattern may be used to chemically etch the metal foil for forming a circuit conductor pattern. Additionally, conductive polymers that match the polymer waveguide in view of the thermal expansion coefficient and elasticity coefficient may be used for the wirings.

The light-emitting or light-receiving element 28 is mounted so as to contact an electrode formed on the optical waveguide layer using flip-chip bonding. Thus, Ag paste or cream solder may be printed or

applied by a dispenser, and then an optical element may be inserted into a guide hole 30 and adhered by heating at about 120°C. In FIG. 3G, when the optical waveguide layer is removed from the substrate by ultrasonic treatment, etc., the embedded hemispheric structures are lifted and included within the optical waveguide layer. Additionally, a lower clad layer 31 may be formed as required. Although not shown, when position discrimination is required, an end of the optical waveguide layer is preferably roughly polished or coated with optical absorber because a reflection from the end causes deterioration of S/N ratio.

The position and number of the light-emitting and light-receiving elements in FIG. 1 are provided only for purpose of clarity of the example, and they are intended to be designed as a whole based on wirings of an electric circuit or pins of an electronic chip that are to be connected in practice. An optical waveguide device according to the present invention may be used to design wirings required for high-speed transmission or EMC measures that provide more improved functionalities and lower costs for development than electrical wirings.

EXAMPLE 2

The device in Example 1 may suffer a large attenuation because light is propagated in all

directions in two-dimension (in a plane of a layer), and the transmission distance may be limited to several centimeters in a gigabit order transmission. Optical power received per 1 mm arc when light propagates for R (mm) is attenuated in an amount expressed by $10*\log(1/2\pi R)+ R*\alpha(dB)$, where α is a propagation loss in dB/mm. Thus, when the light is detected by a light detector having a diameter of 1 mm, the loss of 20 mm propagation is 21 dB even if α is ignored, and 31 dB if the coupling loss of approximately 10 dB is added. Thus, when the application is not a one-to-many transmission such as a clock distribution, directional propagation may be advantageous in terms of power consumption and/or costs.

In this Example, an arrayed light source 41 having an electrical wiring 43 that corresponds to each bit is used as a parallel beam source, as shown in FIG. 4, and light from each light-emitting point 49 is independently propagated as a beam 46 in the same optical waveguide layer (sheet) 40. The emission angle of the beam may be controlled using a microlens, etc. mounted on each surface of the light-emitting point to separately transmit the light as the beam 46 using a planar slab waveguide of several tens centimeters without fabricating a linear waveguide. In this Example, a light direction-

altering structure 44 in the shape of a half cylinder is embedded in an optical waveguide sheet 40 by plating technique similar to Example 1, as shown in FIG. 4, to optically couple each beam and propagate it in the optical waveguide layer 40. The beams are then reflected by a light direction-altering structure 45 also in the shape of a half cylinder, and each beam 47 separately propagated is detected and discriminated in its position by a receiving portion 42 having one-dimensionally arrayed light-receiving regions 50. Instead of a half cylinder, the light direction-altering structure may be a triangular prism laid along, or the optical waveguide layer 40 with its edge cut by 45 degree.

The one-dimensionally arrayed transmitting member 41 and receiving member 42 are surface mounted on the optical waveguide layer 40, and are in electrically contact with an electrical wiring 43 to independently drive each element. They are designed for wirings of an electric circuit or pins of an electronic chip.

In this Example, attenuation of light is reduced to approximately 0.04 dB/mm of a propagation loss in the optical waveguide layer 40 and a coupling loss of 10 dB, and the light attenuation for 300 mm propagation is 22 dB. Thus this is applicable to a wiring from end to end of a typical electric circuit

board. A cross-talk may occur between bits depending on a space between beams. Since this example, however, uses 500 μm pitch and a light-receiving region of 100 μm in diameter, the cross-talk between channels can be reduced to 20 dB or less and the error rate from 10 to 9 or less when the light source power is 1 mW and propagation is as short as about 100 mm. If the cross-talk is a problem, differential output between adjacent light-receiving regions 50 may be taken and electrically processed to avoid the cross-talk problem.

EXAMPLE 3

This example combines planar (in a plane of a layer) transmission of Example 1 and beam transmission of Example 2, further and an optical transmission in a certain directional angle, as shown in FIG. 5.

When a light-emitting element 56a having electrical wirings 54, 55 is mounted out of alignment with the top point of a hemisphere light direction-altering structure 53, beam 58 propagates in a certain angle θ as shown by the reference numeral 59, rather than in all direction of 360 degrees. This enables optical transmission from one transmitting source to multiple receiving portions, but with less power loss and a longer transmission distance in comparison with 360 degree transmission. In FIG. 5,

a transmitting source 56b optically transmits signals two-dimensionally in all direction as in Example 1, and a light source 56c propagates light as a beam in a certain direction as in Example 2. Thus, when optical detectors 57a, 57b and 57c are provided with circularly arranged light-receiving portions as in FIG. 2, 57a detects and discriminates light from light sources 56a, 56b and 56c, 57b detects and discriminated light from light sources 56a and 56b, and 57c detects and discriminates light from a light source 56b. Thus free wiring designs different from electrical wirings is possible.

The planar transmission may provide clock distribution, the transmission in a certain emission angle may provide a one-to-many bus wiring, and the directional beam transmission may provide a one-to-one wiring: a single optical waveguide layer 51 can combine several wiring schemes for multiplexing.

EXAMPLE 4

In this Example, an optical waveguide device as described above is applied to a small portable equipment. To illustrate the Example, FIG. 6 shows a sectional view of a layered substrate that integrates a multilayer buildup substrate and an optical waveguide device. An optical waveguide layer (sheet) in which a light direction-altering structure 77 and/or via wirings 72 are formed as described above

is applied to an electric circuit board 73 in which an electrical wiring 76 and/or via wirings 75 are formed. An electrode for driving an optical element 78, and/or IC 71 in contact with through-hole electrodes 72 from the substrate 73 are mounted on the surface of the layered substrate 70.

In FIG. 6, the reference numeral 74 is an RF circuit portion for wireless communication that is covered with a shield cover to avoid electromagnetic interference. Traditionally, a signal wire drawn from an RF circuit portion may serve as an antenna depending on the length of the signal wire, causing faulty operation of its own circuit due to a common mode noise radiation, or resulting in an extensive design time in order to satisfy the standards imposed by the Radio Law. In this example, an optical signal wiring as shown by the reference numeral 79 using a combined electric/optical substrate 70 according to the invention can significantly reduce unwanted radiation because it does not form an antenna.

In the future wireless communication, a number of high-speed schemes using different frequencies, such as IEEE802.11a (5 GHz band, 54 Mbps), Bluetooth (2.4 GHz, 1 Mbps) and the fourth generation mobile phones (5 GHz band, 100 Mbps) is likely to coexist, and this will require EMC design for a small mobile phone and wirings that can be changed in their

architecture in situ. A combined electric/optical substrate integrated with an optical waveguide device such as one according to the invention can increase design flexibility thereof and reduce costs.

In FIG. 6, although an optical waveguide layer (sheet) is applied onto an electric circuit board 73, and electronic chips 71, etc. are further mounted thereon, an optical waveguide layer (sheet) may of course be embedded within a multilayer buildup substrate.

EXAMPLE 5

Above Examples describe exemplary optical waveguide layers of a single layer. A buildup combined electric/optical substrate with a multi-layered optical waveguide layer may allow faster data transfer. FIG. 7 shows a board 230 combined with high-speed bus, etc. using such optical wirings. The board has a dual CPU (231) configuration, and accesses between CPUs 231 and between CPUs 231 and memory devices 232 are arranged using an optical waveguide device (using beams 234, etc.) according to the invention. Four layers of optical waveguide layer (sheet) 236 are stacked up as shown in FIG. 7, and the board 230 has 4 × 4, or 16 bit-configuration in the surface direction by multiplexing 4 bits using directional beams as described in Example 4. In this example, light-receiving/light-emitting elements are

mounted so as to provide bi-directional transmission. Additionally, 64 bit-output of the CPU may be parallel-to-serial converted to obtain 16 bits and optically transmit signals in 10 Gbps per bit: this provides for a 160 Gbps (20 Gbite/sec) serial connection for one entire channel at 2.5 GHz operation per bit (64 bit equivalent).

An access to the memory 232 is a bus wiring capable of a one-to-many, 8 bit transmission in 4 layers, using a 90 degree emission angle of 2 bit as shown in Example 3. FIG. 7 shows a certain directional angle transmission from the CPU 231 to the memory 232, as is a transmission from the memory 232 to the CPU 231. A clock generator 233 using an Xtal integrated element simultaneously distributes clocks to two CPUs 231 through planar transmission as in Example 1. The clocks may be repeated at relay points 235 (where the clocks are reproduced and transmitted using OE and EO conversion) according to the size of the board and distributed to required areas in the substrate using, for example, a 90 degree emission angle transmission, as appropriate.

I/O ports, which are not shown, are connected using conventional electrical wirings in the multilayer electric circuit board portion 237. Optical wirings, however, may also be applied for this purpose as described above.

With arrangements described above, high-speed connectivity is provided, while EMI noises are suppressed and a multi-CPU system may be constructed to directly connect a plurality of CPUs together or peripheral devices together, which are remotely located, via a network. The width of a path, positions, amounts, wiring scheme and the like between elements are not limited to those in FIG. 7.

Current buildup substrates made up only of electrical wirings present challenges of how cross-talk noises caused by closely located wirings, signal degradation caused by a reflection due to an impedance mismatch, etc. and resulting electromagnetic radiation noises should be solved in a high-speed signal wirings. Additionally, a high-speed serial transmission is being explored as a bus for a next generation high-speed LSI connectivity, and RapidIO (Motrola, USA, etc.), Hyper Transport (AMD, USA, etc.), 3GIO (Intel, USA, etc.) and the like is being developed with a current target of 1 Gbyte/sec at 1 GHz in 8 bit. If 10 Gbyte/sec or more is required with the same specifications in further next generation, combined high-speed wirings with positional multiplexing using optical waveguide devicees according to the present invention will be effective in terms of electromagnetic radiation noises, board design and power consumption.

As described above, a multiplexed optical wiring that facilitates the construction of unrestricted wiring architecture may be provided according to the invention in an optical waveguide device that may be utilized for high-speed wirings in an electric circuit board or electromagnetic noise measures, without complex waveguide structures at a low cost. The apparatus may be used for a part of wirings on an electrical board on which LSIs, etc. are mounted to provide a multilayer substrate so that EMI measures can be implemented without major design modifications at a low cost. Additionally, high-speed bus wirings that provide additional design flexibility of a board are provided by a multilayer substrate according to the invention in the construction of, for example, a high-speed multi-CPU system.